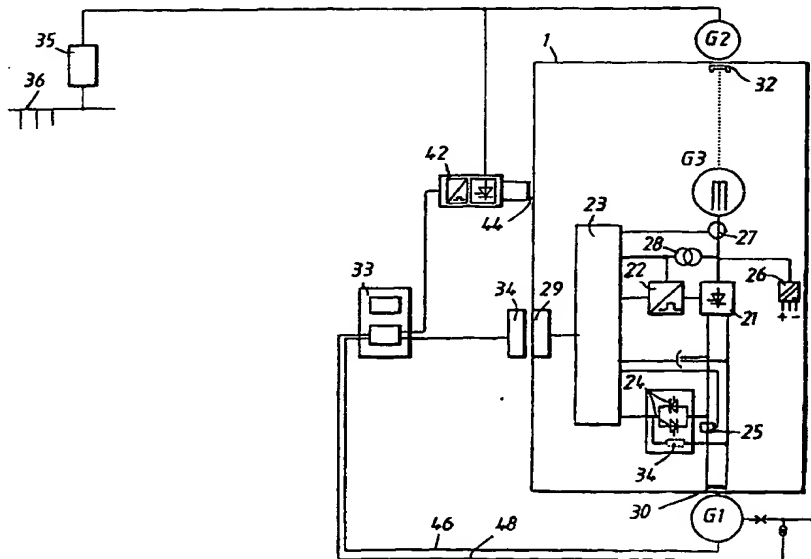


## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification <sup>6</sup> : <b>H02K 19/36</b>		<b>A2</b>	(11) International Publication Number: <b>WO 99/17433</b>
			(43) International Publication Date: 8 April 1999 (08.04.99)
(21) International Application Number: PCT/SE98/01738 (22) International Filing Date: 29 September 1998 (29.09.98) (30) Priority Data: 9703552-1      30 September 1997 (30.09.97)      SE (71) Applicant (for all designated States except US): ASEA BROWN BOVERI AB [SE/SE]; S-721 83 Västerås (SE). (72) Inventors; and (75) Inventors/Applicants (for US only): LEIJON, Mats [SE/SE]; Hyvlgatan 5, S-723 35 Västerås (SE). SÖRENSEN, Erland [SE/SE]; Gudruns Väg 32, S-723 55 Västerås (SE). KARLSSON, Thommy [SE/SE]; Nyvå, S-740 22 Bålänge (SE). (74) Agent: HOPFGARTEN, Nils; L.A. Groth & Co. KB, P.O. Box 6107, S-102 32 Stockholm (SE).		(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, CZ (Utility model), DE, DE (Utility model), DK, DK (Utility model), EE, ES, FI, FI (Utility model), GB, GE, GH, GM, HR, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SK (Utility model), SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).  <b>Published</b> <i>In English translation (filed in Swedish).          Without international search report and to be republished          upon receipt of that report.</i>	

(54) Title: AN ELECTRIC POWER PLANT



## (57) Abstract

An electric power plant comprises at least one rotating electric machine (G1), intended to be connected directly to a distribution or transmission network and comprising at least one electric winding. The winding comprises at least one electric conductor, a first layer with semiconducting properties surrounding the conductor, an insulating layer surrounding the first layer, and a second layer with semiconducting properties surrounding the insulating layer. Further, a brushless excitation system (1, 33, 34, 42, 44) is adapted to excite the electric machine.

**FOR THE PURPOSES OF INFORMATION ONLY**

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece			TR	Turkey
BG	Bulgaria	HU	Hungary	ML	Mali	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MN	Mongolia	UA	Ukraine
BR	Brazil	IL	Israel	MR	Mauritania	UG	Uganda
BY	Belarus	IS	Iceland	MW	Malawi	US	United States of America
CA	Canada	IT	Italy	MX	Mexico	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NE	Niger	VN	Viet Nam
CG	Congo	KE	Kenya	NL	Netherlands	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NO	Norway	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	NZ	New Zealand		
CM	Cameroon			PL	Poland		
CN	China	KR	Republic of Korea	PT	Portugal		
CU	Cuba	KZ	Kazakstan	RO	Romania		
CZ	Czech Republic	LC	Saint Lucia	RU	Russian Federation		
DE	Germany	LI	Liechtenstein	SD	Sudan		
DK	Denmark	LK	Sri Lanka	SE	Sweden		
EE	Estonia	LR	Liberia	SG	Singapore		

## AN ELECTRIC POWER PLANT

### Technical Field

The present invention relates to an electric power plant comprising at least one rotating main electric machine, intended to be connected directly to a distribution and transmission network and comprising at least one electric winding. The invention relates also to the use of a rotating electric machine in an electric power plant.

### 10 Background

The rotating electric machine, which is included in the power plant, may for example be a synchronous machine, a double-fed machine, an external pole machine or a synchronous flux machine.

15 A transformer has been used up to the present to step-up the voltage to the level of the network i.e., in the range of 130 - 400 kV in order to connect machines of the type mentioned above to distribution or transmission networks, commonly referred to below as power networks.

A generator with a rated voltage of up to 36 kV is described by Paul Siedler in an article entitled "36 kV Generators Arise from Insulation Research", in 20 Electrical World, 15 October 1932, pp. 524-527. These generators comprise windings of high voltage cable, in which the insulation is divided into different layers having different dielectric constants. The insulation material being utilized consists of different combinations of the following three components: mica foil-mica, lacquer and paper.

25 It has proved that, by manufacturing the above-mentioned winding for the machine of an insulated electric high voltage conductor having a solid insulation of a similar type as for cables for the transmission of power, the voltage of the machine may be increased to such levels that the machine may be connected directly to any power network without an intermediate transformer. The transformer may 30 thus be dispensed with. A typical power range for these machines is 30 - 800 kV.

The aim of the present invention is to provide an electric power plant having at least one main electric machine which is directly connected to transmission

and distribution networks and which is magnetizable from an excitation system which lacks slip rings and is simple to maintain.

#### Summary of the invention

5 This aim is achieved by an electric power plant of the kind described in the introductory part of the description, with the characteristic features described in Claim 1.

The insulated conductor or high voltage cable used in the present invention is flexible and bendable and of the type described in more detail in WO 10 97/45919 and WO 97/45847. Additional descriptions of the insulated conductor or cable can be found in WO 97/45918, WO 97/45930 and WO 97/45931.

Thus, in a device according to the invention the windings are preferably composed of cables having solid, extruded insulation, of a type currently used for power distribution, such as XLPE cables or cables having EPR insulation. Such a 15 cable comprises an inner conductor composed of one or more strands, an inner semiconducting layer surrounding the conductor, a solid insulating layer surrounding the inner semiconducting layer and an outer semiconducting layer surrounding the insulating layer. Such cables are bendable, which is an important property in this respect since the technology for the machines of the invention, is based pri- 20 marily on a winding system in which the winding is formed from cables which are bent during assembly. The bending ability of an XLPE cable normally corresponds to a radius of curvature of approximately 20 cm for a cable with a diameter of 30 mm, and a radius of curvature of approximately 65 cm for a cable with a diameter of 80 mm. In the present application the designation bendable is used to indicate 25 that the winding is bendable down to a radius of curvature in the order of four times the cable diameter, preferably eight to twelve times the cable diameter.

The winding should be constructed so as to retain its properties even when it is bent and when it is subjected to thermal or mechanical stress during operation. It is vital that the layers retain their adhesion to each other in this re- 30 spect. The material properties of the layers are decisive here, particularly their elasticity and relative coefficients of thermal expansion. In an XLPE cable, for example, the insulating layer consists of cross-linked, low-density polyethylene, and

the semiconducting layers consist of polyethylene with both soot and metal particles mixed therein. Changes in the volume as a result of temperature fluctuations are completely absorbed as changes in the radius of the cable and, thanks to the comparatively slight difference between the coefficients of thermal expansion of the layers in relation to the elasticity of these materials, the radial expansion of the cable may take place without the loss of adhesion between the layers.

The material combinations stated above should be considered by way of example only. Other combinations fulfilling the specified conditions as well as the condition of being semiconducting, i.e. having a resistivity within the range of  $10^{-1}$  -  $10^6$  ohm-cm. e.g. 1 -500 ohm-cm or 10 - 200 ohm-cm naturally also fall within the scope of the invention.

The insulating layer may consist, for example, of a solid thermoplastic material such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polybutylene (PB), polymethyl pentene (PMP), cross-linked materials such as cross-linked polyethylene (XLPE), or rubber such as ethylene propylene rubber (EPR) or silicone rubber.

The inner and outer semiconducting layers may be of the same basic material but with particles of conducting material such as soot or metal powder mixed therein.

The mechanical properties of these materials, particularly their coefficients of thermal expansion, are affected relatively little by whether soot or metal powder is mixed therein or not, i.e. in the proportions required to achieve the conductivity necessary according to the invention. Thus, the insulating layer and the semiconducting layers have substantially the same coefficients of thermal expansion.

Ethylene-vinyl-acetate copolymers/nitrile rubber, butyl graft polyethylene, ethylene-acrylate copolymers and ethylene-ethyl-acrylate copolymers may also constitute suitable polymers for the semiconducting layers.

Even when different types of material are used as a base in the various layers, it is desirable for their coefficient of thermal expansion to be substantially the same. This is the case in the combination of the materials listed above.

The materials listed above have a relatively good elasticity, with an E-modulus of  $E < 500$  MPa, preferably  $< 200$  MPa. The elasticity is sufficient for any

minor differences between the coefficients of thermal expansion for the materials in the layers to be absorbed in the radial direction by the elasticity so that no cracks or other damage arise and so that the layers are not released from each other. The material in the layers is elastic, and the adhesion between the layers is at least of the same magnitude as the weakest of the materials.

The conductivity of the two semiconducting layers is sufficient to substantially equalise the potential along the respective layers. The conductivity of the outer semiconducting layer is sufficiently large to contain the electric field in the cable, but at the same time sufficiently small to not give rise to significant losses due to currents induced in the longitudinal direction of the layer.

Thus, each of the two semiconducting layers essentially constitutes one equipotential surface, and these layers will substantially enclose the electric field between them.

This does not, of course, exclude one or several semiconducting layers from being arranged additionally in the insulating layer.

According to advantageous embodiments of the power plant according to the invention, the brushless excitation system comprises a rotating part with an exciter connected to rotating controllable semiconductor elements with associated control equipment for rectifying the supply voltage obtained for supplying the field winding of the machine, and furthermore a communication unit is adapted for wireless communication between stationary regulator equipment and the control equipment which is included in the rotating part. By exploiting the controllable semiconductor elements in this way, improved regulating properties are achieved in that positive as well as negative excitation voltages can be achieved simultaneously with the simple maintenance characterizing brushless excitation systems. Faster response and transient times are obtained during network interference in that the excitation system can generate positive as well as negative excitation voltage.

According to other advantageous embodiments of the power plant according to the invention, the exciter is designed with double stator windings for the excitation of the main electric machine as well as the auxiliary power machine. The stator windings are hereby advantageously connected to each of their re-

spective controllable semiconductor elements with respective control equipment for individual control of the supply of the auxiliary power machine and the main electric machine. The control equipments are advantageously adapted to generate control pulses to the controllable semiconductor elements in a manner self-compensating for variations in the supply voltage to the semiconductor elements. Flux changes necessary for voltage variations suited to the excitation requirements of the machine will thereby not influence the excitation of a voltage regulated machine generating auxiliary power. A constant voltage at the auxiliary power busbar and a voltage rise for the generation of extra, temporary short-circuit power during faults are enabled by voltage regulation of the machine generating auxiliary power.

#### Brief description of the drawings

To explain the invention in greater detail, embodiments of the electric power plant according to the invention will now be described in more detail with reference to the accompanying drawings, wherein

Figures 1 to 3 show diagrams of three different embodiments of the power plant according to the invention,

Figure 4 shows a more detailed embodiment of the rotating part in the excitation system in connection with the embodiments according to Figures 1-3,

Figure 5 illustrates a principle for reduction of exciter losses by supply voltage, which is adapted to the requirements, to the controllable, rectified semiconductor elements in the form of a rotating thyristor bridge,

Figure 6 illustrates a principle for self-compensating control pulse generation for control of the rectifying semiconductor elements, and

Figure 7 shows a cross-section view of the insulated conductor which is used in machines in the power plant according to the invention.

Description of the preferred embodiments

Figure 1 shows a first embodiment of the electric power plant according to the invention, comprising an electric machine G1 and an auxiliary power machine in the form of a permanent-magnet generator G2. The machine G1 is excited by means of an excitation system comprising a rotating part 1 with an exciter G3, controllable rectifying semiconductor elements in the form of a thyristor bridge 21 with a control-pulse generator 22, a bidirectional overvoltage protection device 24, and a rotating field winding 30 of the electric machine G1. Further, the rotating part 1 comprises control equipment 23 for control of the thyristor bridge 21 via the control pulse generator 22. The control equipment 23 is also connected to current-measuring members 25, 27 arranged on each side of the thyristor bridge 21. A filter transformer 28 is connected between the output side of the exciter G3 and the control pulse generator 22 and the control equipment 23 for determining and rotating the phase position for firing the thyristors for the purpose of voltage adaptation. Variations of the input voltage may thus be compensated for by control of the thyristor firing.

The rotating part 1 of the excitation system further comprises a supply device 26 for the electronic devices of the rotating part 1.

A bidirectional overvoltage protection device 24 serves as overvoltage protection for the field winding 30 and diverts induced currents in case of a fault. The overvoltage protection device 24 comprises a current-limiting resistor 34, which makes possible continued operation when the overvoltage protection device 24 is activated. An activated protection device 24 is reset by temporary sign reversal of the field voltage.

The control equipment 23 is further connected to a rotating communication unit 29 for wireless communication with a stationary communication unit 34, which in turn is connected, via the control equipment 23, to regulator equipment 33 for control of the power stage, formed by the thyristor bridge 21 and the control pulse generator 22, from the regulator equipment 33. In this way, the excitation of the machine G1 is thus controlled from the stationary regulator equipment 33 by regulating the degree of modulation of the thyristors of the bridge 21.

Other monitoring and regulating functions may also be carried out from the stationary regulator equipment 33.

The signal transmission between the stationary and rotating communication units 34, 29 may be performed with the aid of frequency-modulated infrared light. Each unit 34, 29 is then provided with at least one transmitting and one receiving part, comprising a number of light-emitting diodes. The number of light-emitting diodes and the location on the rotating part 1 are such that no blind angles may occur between the transmitting and the receiving units.

Alternatively, the communication between the stationary and rotating communication units 34, 29 may take place capacitively or inductively, or by radio communication.

The rotating exciter G3 is of synchronous-machine type with a rotating stator winding, which is excited by a smaller static exciter, comprising converters 42 for supplying the stationary field winding 44. The static exciter is supplied from the auxiliary power generator G2 and the excitation is controlled by the regulator equipment 33 by controlling the supply voltage of the converter bridge 42. The supply voltage to the thyristor bridge 21, which in turn supplies the field winding 30 of the machine G1, may thus be regulated by changing the magnetic flux in the rotating exciter G3.

The auxiliary power generator G2 further supplies a busbar 36 for distribution of the auxiliary power via equipment 35 for voltage, and possibly frequency, adaptation.

The output voltage of the machine G1 is fed back, via a connection 46, to the regulator equipment 33 for automatic adaptation of the supply voltage of the rectifying semiconductor elements 21 to the actual operating conditions.

By such a requirement-adapted control of the supply voltage of the thyristor bridge 21, the losses in the rotating exciter G3 are reduced. In case of transients currents, the field voltage may be increased. Stationary operation stability thus entail a low peak-voltage factor and transient stability entails a high peak-voltage factor. The peak-voltage factor may be defined as the ratio of the maximum possible field voltage and the field voltage at rated load and a hot field winding. Compare with the description of Figure 5 below.

During stationary operating conditions, the voltage of the exciter G3 is thus increased or decreased in proportion to the desired value fed into the regulator equipment 33. During transient stability and voltage regulation (the regulator may alternatively be arranged as a field-current regulator), the supply voltage is increased to a maximum value until stationary operation stability has been re-  
5 stored. The return to the actual voltage level for stationary operation stability may then be performed either instantaneously or via a ramp function with a controlled rate of change. The control pulse generator 22, with the function of compensating the firing instants of the thyristors 21 in case of voltage variations, maintains the  
10 field current constant during the transition process.

The line voltage may be fed back to the regulator equipment 33, via a connection 48, for use when phasing the machine G1.

Figure 2 shows an alternative embodiment, in which the auxiliary power generator G2 is a synchronous machine and the rotating part 1 comprises an ex-  
15 citer G3 in the form of a permanent-magnet generator with double stator windings for excitation of the machine G1 and the auxiliary power generator G2 via a respective thyristor bridge included in the rotating part 1. In this embodiment, the rotating part 1 thus comprises a unit 51 of a power stage, an overvoltage protection device and control equipment for supplying the field winding 30 of the ma-  
20 chine G1, as well as similar devices, represented by the block 52 in Figure 2, for supplying the auxiliary power generator G2.

In the same way as the control equipment 23 for the excitation of the main machine G1 is connected to stationary regulator equipment 53 via communication units 29, 34 for wireless communication, as described with reference to Figure 1,  
25 the corresponding control equipment for the excitation of the auxiliary power generator G2 is connected to the regulator equipment 53 via identical communication units 54, 57. In this embodiment, the regulator equipment 53 comprises two voltage regulators 58, 59 for maintaining constant the voltages of both the machine G1 and the auxiliary power generator G2 by excitation control.

30 The permanent-magnet generator G3 comprises a stationary permanent-magnet rotor 60, supplemented by a few winding turns 61, which are supplied via the converter 62 from the auxiliary power generator G2 for controlled flux

changes. In such a permanent-magnet rotor 60, there is always a field even at zero voltage.

The control pulse generation for the thyristor bridges is based on a principle for self-compensation for variations in the supply voltage of the thyristor bridges. Flux changes which are necessary for voltage variations for adaptation to the excitation requirement of the machine G1 will thus not influence the excitation of the voltage-regulated auxiliary power generator G2.

The voltage regulation of the auxiliary power generator G2 is made possible by the voltage regulator 58 included in the regulator equipment 53, which voltage regulator makes it possible either to maintain a constant voltage on the auxiliary power busbar 36, ALT. 2, or to increase the voltage for temporary generation of extra short-circuit power in case of a fault, ALT. 1. The voltage of the auxiliary power generator G2 is thus increased by increasing its excitation.

In the embodiment shown in Figure 2, the auxiliary power generator G2 is a synchronous machine, as mentioned above, of a size smaller than that of machine G1. Also the power stage 52 for supplying the field to the auxiliary power generator G2 is smaller than the corresponding power stage 51 for supplying the field of the machine G1.

The other parts of the embodiment of Figure 2 are identical with the corresponding parts of the embodiment shown in Figure 1 and will therefore not be described in more detail here.

Figure 3 shows another embodiment of the power plant according to the invention. This embodiment differs from the embodiment shown in Figure 2 in that the exciter G3 is of an asynchronous machine type with double rotor windings for excitation of the machine G1 and the auxiliary power generator G2.

The asynchronous machine G3 with reversed direction of rotation functions as a rotating transformer and also makes possible excitation during downtime.

In addition to the change of the exciter G3 described above, this embodiment corresponds to the one described in Figure 2 and will not, therefore, be described in more detail here.

Figure 4 shows in more detail an embodiment of the rotating part 1 in the embodiments according to the preceding figures. The rotating part 1 thus comprises a part 71 for excitation and protection of the machine G1. The part 71 comprises a thyristor bridge 81 with a control pulse generator 82, which has been described above, connected to the output of a selector 83, which is adapted to select the smallest of an input signal in the form of a control signal from the regulator device (not shown), received over the wireless communication units 93, 94, and a signal from a regulator unit 85. This regulator unit 85 is adapted to receive, as input signals, a set-point or limit-value signal from the communication unit 93 as well as a signal representing the field current  $I_{\text{field}}$ , measured by means of the current-measuring device 95, for manual control or limitation of the field current.

Further, a current-measuring unit 86 is connected to the communication unit 93 and to the current transformers 87 for measuring the alternating currents from the rotating exciter G3, in this case of a permanent-magnet generator type, and supplying corresponding measurement signals  $I_r$ ,  $I_s$ ,  $I_t$  to the communication units 93.

The current on both the direct-voltage side and the alternating-voltage side is measured with the current-measuring devices 95 and 86, 87, respectively, and the difference current is used as a criterion for resetting the overvoltage protection device 84, the resetting being performed with the aid of a temporary negative excitation voltage.

A voltage-measuring unit 89 is adapted to measure the voltage on the output of the rotating exciter G3 with a filter transformer 88, as described above, and to supply corresponding signals  $U_r$ ,  $U_s$ ,  $U_t$  to the communication unit 93. The voltage signal sensed by the transformer 88 is also supplied to the control pulse generator 82, where it is compared with the signal from the selector 83 for controlling the thyristor bridge 81 in dependence thereon.

Still another voltage-measuring unit 70 is adapted to measure the field voltage and to supply a corresponding measurement signal  $U_{\text{field}}$  to the communication unit 93 for transmission to the stationary communication unit 94 and the regulator equipment.

Further, there is a bidirectional overvoltage protection device 84 for the field winding 64 of the machine G1 as previously described.

A unit 71 for detection of ground fault in the field winding 64 as well as a transducer 72 for measuring the temperature of the field winding 64 are also provided.

Figure 4 further shows the permanent-magnet rotor 60 of the exciter G3 with a supplementary winding 61, as described with reference to Figure 2, as well as a feedback connection 46 from the machine G1 to the regulator equipment and a connection 48 for supplying a measured line voltage to the regulator equipment, as described with reference to Figure 1.

Figure 5 shows a diagram illustrating a solution in principle for reduction of exciter losses by adapting the requirement of the supply voltage to the rotating thyristor bridge.  $U_{fl/0}$  designates the field voltage in an unloaded machine,  $U_{fl/1}$  designates the field voltage at rated load on the machine,  $U_{fc}$  designates maximum field voltage during stationary operation (stationary operation stability),  $U_{peak}$  designates maximum field voltage during transient operation (transient stability),  $U_{ac}$  designates the supply voltage of the thyristor bridge, and  $U_{dc}$  designates the actual field voltage  $= 1.35 \times U_{ac} \times \cos a$ .

In case of transient disturbances, the maximum field voltage  $U_{peak}$  thus increases, at  $t_1$ , as does the peak-voltage factor, which is defined above. In this way, improved efficiency of the rotating exciter during steady-state conditions is obtained.

Figure 6 illustrates in more detail the principle of self-compensating control-pulse generation for the thyristor bridge in the power plant according to the invention.

From the filter transformer 88, the control pulse generator 82 is supplied with the phase voltages  $U_R$ ,  $U_S$ ,  $U_T$  (cf. Figure 4 and the upper curve of Figure 6). An internal auxiliary voltage  $U+R$ , which is shifted in phase 60 electrical degrees from the phase voltage  $U_R$ , is generated. The output signal  $UC$  of the regulator 83, 85 in Figure 4 is supplied to the control pulse generator 82 and is compared in a comparator with the auxiliary voltage  $U+R$  and when the signal  $UC$  is equal to the auxiliary voltage  $U+R$  and  $U_S$  is greater than  $U_R$ , a firing signal is

supplied to the relevant thyristor in the S-phase in the bridge 81 in Figure 4, marked in the lower part of Figure 6, whereupon the conduction interval of the thyristor follows.

The firing instant is thus controlled both by the changes in the regulator  
5 signal  $U_c$  and by changes in the signal level of the internal auxiliary voltage  $U+R$ .

To enable direct connection of the electric machine and possibly the auxiliary power machine, as previously discussed, the machine has windings, comprising an insulated conductor of the kind shown in Figure 7. Figure 7 thus shows a  
10 cross-section view of an insulated conductor 11 comprising a number of strands 35 with a circular cross section of, for example, copper (Cu). These strands 35 are arranged in the centre of the insulated conductor 11. A first semiconducting layer 13 is arranged around the strands 35. An insulating layer 37, for example an XLPE insulation, is arranged around the first semiconducting layer 13. A second semiconducting layer 15 is arranged around the insulating layer 37. The insulating  
15 conductor or cable is bendable and this property is maintained in the insulated conductor during its service life, and the three layers mentioned are designed so as to adhere to one another even when the cable is bent. The insulated conductor has a diameter in the interval 20-250 mm and a conductor area in the interval 80-3000 mm<sup>2</sup>.

20 A plurality of modifications of the embodiments described above are, of course, possible. Thus, for example, the phase position for the supply voltage of the converter may be transformed to the stationary side, which makes possible a stationarily arranged control pulse generator and transmission of the starting instant of the firing pulses to the rotating part in a wireless manner, as described  
25 above. Further, for example, the supply voltage to the rotating supply part may be transformed to the rotating part by means of a ring transformer. According to additional possible alternatives, current, voltage and temperature measurement may be realized by the use of fibre-optic technology.

---

## CLAIMS

1. An electric power plant, comprising at least one rotating electric machine, intended to be connected directly to a distribution or transmission network and  
5 comprising at least one electric winding, **characterized** in that the winding comprises at least one electric conductor, a first layer with semiconducting properties surrounding the conductor, an insulating layer surrounding the first layer, and a second layer with semiconducting properties surrounding the insulating layer, and in that a brushless excitation system is adapted to excite the electric machine.
- 10 2. A power plant according to claim 1, **characterized** in that the potential of the first layer is essentially equal to the potential of the conductor.
3. A power plant according to claim 1 or 2, **characterized** in that the second  
15 layer is adapted to form essentially an equipotential surface surrounding the conductor.
4. A power plant according to claim 3, **characterized** in that the second layer is connected to a predetermined potential.
- 20 5. A power plant according to claim 4, **characterized** in that said predetermined potential is ground potential.
6. A power plant according to any of the preceding claims, **characterized** in  
25 that at least two adjacent layers of the winding of the machine have essentially equal coefficients of thermal expansion.
7. A power plant according to any of the preceding claims, **characterized** in  
30 that the conductor comprises a number of strands, at least some of which being in electrical contact with one another.

8. A power plant according to any of the preceding claims, **characterized** in that each one of said three layers is fixed to adjacent layers along essentially the whole contact surface.
- 5 9. A power plant according to any of the preceding claims, **characterized** in that said layers are adapted to adhere to one another even when the insulated conductor is bent.
- 10 10. An electric power plant, comprising at least one electric machine of alternating-current type, intended to be connected directly to a distribution or transmission network and comprising at least one magnetic core and at least one electric winding, **characterized** in that the winding is formed from a cable comprising one or more current-carrying conductors, each conductor having a number of strands, an inner semiconducting layer arranged around each conductor, an insulating layer of solid insulating material arranged around said inner semiconducting layer, and an outer semiconducting layer arranged around the insulating layer, and in that a brushless excitation system is adapted to excite the electric machine.
- 15 11. A power plant according to claim 10, **characterized** in that said cable comprises a sheath.
- 20 12. A power plant according to any of the preceding claims, **characterized** in that the brushless excitation system comprises a rotating part with an exciter, connected to controllable semiconductor elements with associated control equipment for rectifying the supply voltage obtained for supplying the field winding of the machine.
- 25 13. A power plant according to claim 12, **characterized** in that a communication unit is adapted for wireless communication between stationary regulator equipment and the control equipment included in the rotating part.
- 30

14. A power plant according to claim 12 or 13, **characterized** in that the exciter is of synchronous machine type with a rotating stator winding.

15. A power plant according to claim 12 or 13, **characterized** in that the exciter comprises a permanent-magnet generator, in which stationary permanent magnets are supplemented by winding turns for controlled changes of the flux.

16. A power plant according to claim 12 or 13, **characterized** in that the exciter comprises an asynchronous machine with three rotating windings and reversed direction of rotation.

17. A power plant according to any of claims 12 - 16, comprising a machine for auxiliary power generation, **characterized** in that the exciter is designed with double stator windings for supplying the electric machine or the main machine as well as the auxiliary power machine.

18. A power plant according to claim 17, **characterized** in that the stator windings are connected to each of their respective controllable semiconductor elements with respective control equipment for individual control of the supply of the auxiliary power machine and the electric machine.

19. A power plant according to claim 17 or 18, **characterized** in that the control equipments are adapted to generate control pulses to the controllable semiconductor elements in a manner self-compensating for variations in the supply voltage to the semiconductor elements.

20. A power plant according to any of claims 12-19, **characterized** in that the controllable semiconductor elements are adapted to form a thyristor bridge.

21. A power plant according to any of claims 12-20, **characterized** in that a filter transformer is adapted to determine the phase position for firing the controllable semiconductor elements for adaptation of the voltage.

22. A power plant according to any of claims 13-21, **characterized** in that the communication unit comprises stationary transmitters and/or receivers connected to the regulator equipment as well as receivers and/or transmitters on the rotating part connected to the control equipment for communication therebetween with frequency-modulated infrared light.

23. A power plant according to any of claims 17-22, **characterized** in that the auxiliary power machine is adapted, via the converter, to supply the stationary field winding of the rotating exciter.

24. A power plant according to any of claims 17-23, **characterized** in that the output voltage of the auxiliary power machine is fed back, via a regulator, to the controllable semiconductor elements for the auxiliary power machine for regulating the voltage by excitation control.

25. A power plant according to any of claims 13-24, **characterized** in that the stationary part and the rotating part of the communication unit are adapted for wireless communication, capacitively or inductively or by radio communication or optical connection.

26. A power plant according to any of the preceding claims, **characterized** in that a unit is adapted to detect ground faults in the supply of the field winding of the electric machine.

27. A power plant according to any of the preceding claims, **characterized** in that transducers are adapted to measure the temperature in the field winding of the electric machine.

28. A power plant according to any of claims 12-27, **characterized** in that an overvoltage protection device, controlled by the control equipment, is connected across the field winding of the electric machine.

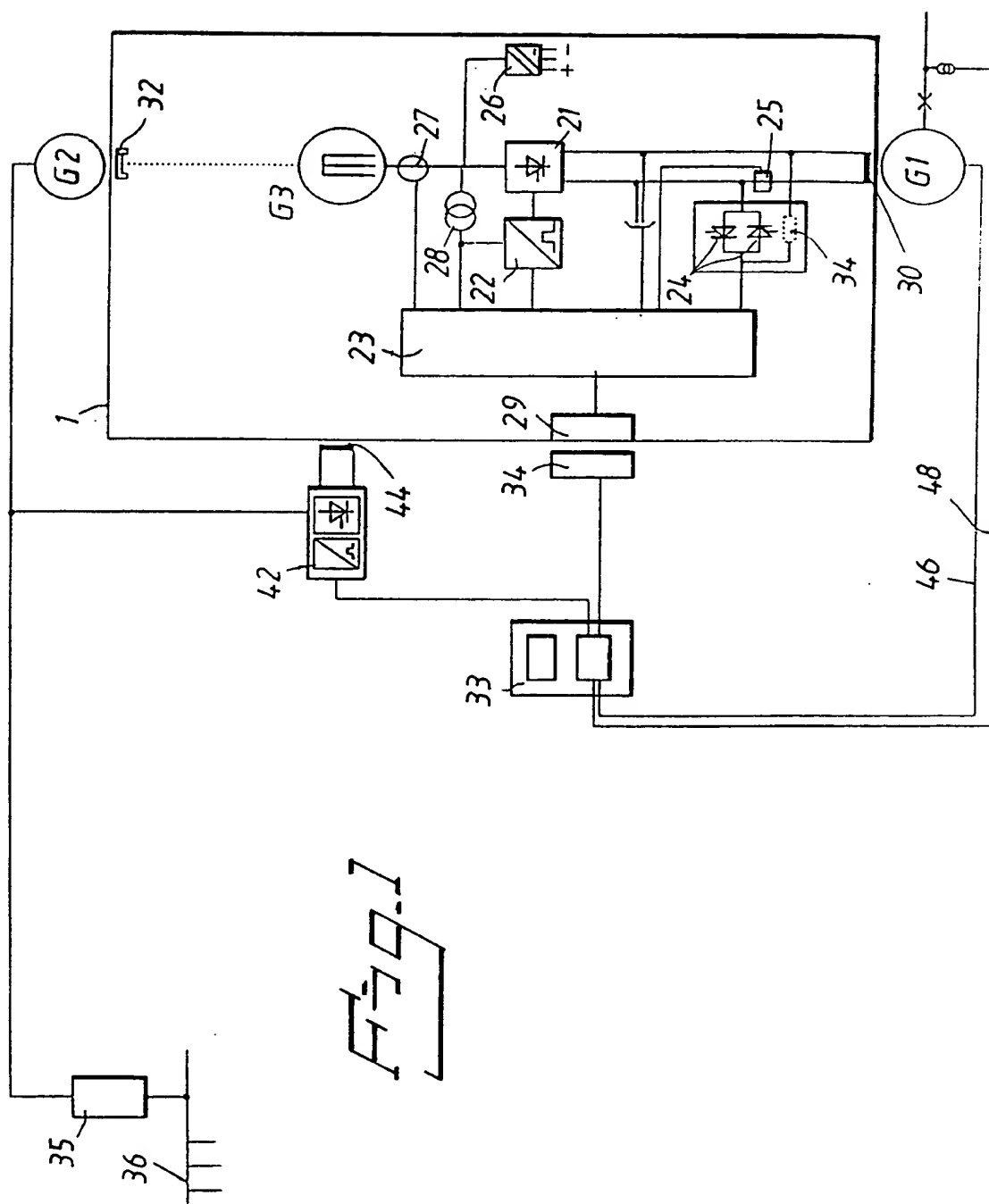
29. A power plant according to claim 28, **characterized** in that current-measuring means are arranged on the AC and DC sides of the controllable semiconductor elements, and that the overvoltage protection device is adapted to be  
5 reset in response to the difference between these currents fulfilling a predetermined condition.

30. A power plant according to any of claims 13-29, **characterized** in that the output voltage of the electric machine is fed back to the regulator equipment for  
10 adaptation of the supply voltage to the actual operating conditions.

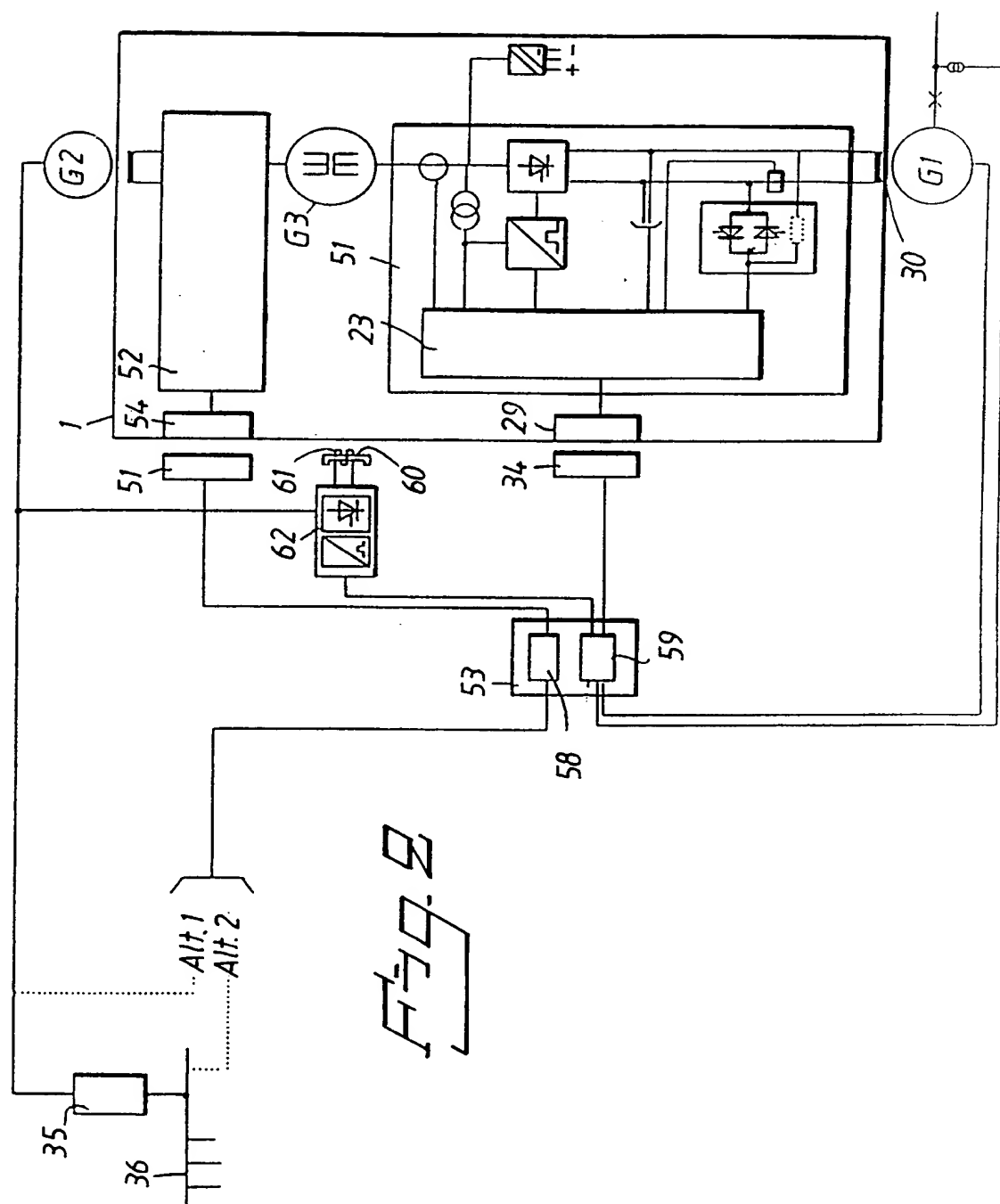
31. A power plant according to any of claims 17-30, **characterized** in that the auxiliary power machine comprises at least one electric winding with at least one electric conductor, a first layer with semiconducting properties surrounding the  
15 conductor, an insulating layer surrounding the first layer, and a second layer surrounding the insulating layer.

32. Use of a rotating electric machine in an electric power plant according to any of the preceding claims, said machine being intended to be connected directly  
20 to a distribution or transmission network and comprising at least one electric winding, said winding comprising at least one electric conductor, a first layer with semiconducting properties surrounding the conductor, an insulating layer surrounding the first layer, and a second layer with semiconducting properties surrounding the insulating layer, and a brushless excitation system for exciting the  
25 electric machine.

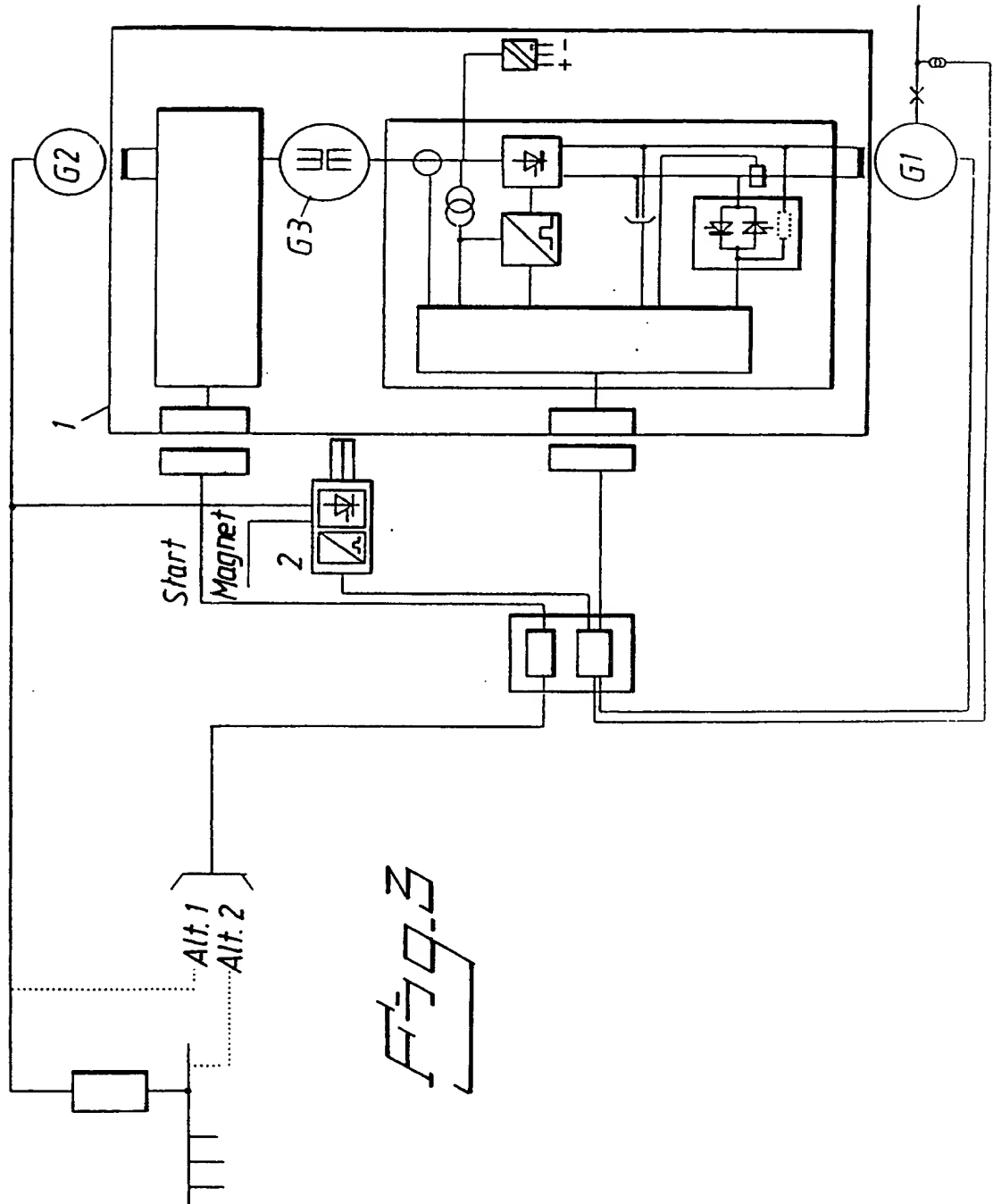
---



2 / 5



3 / 5



4 / 5

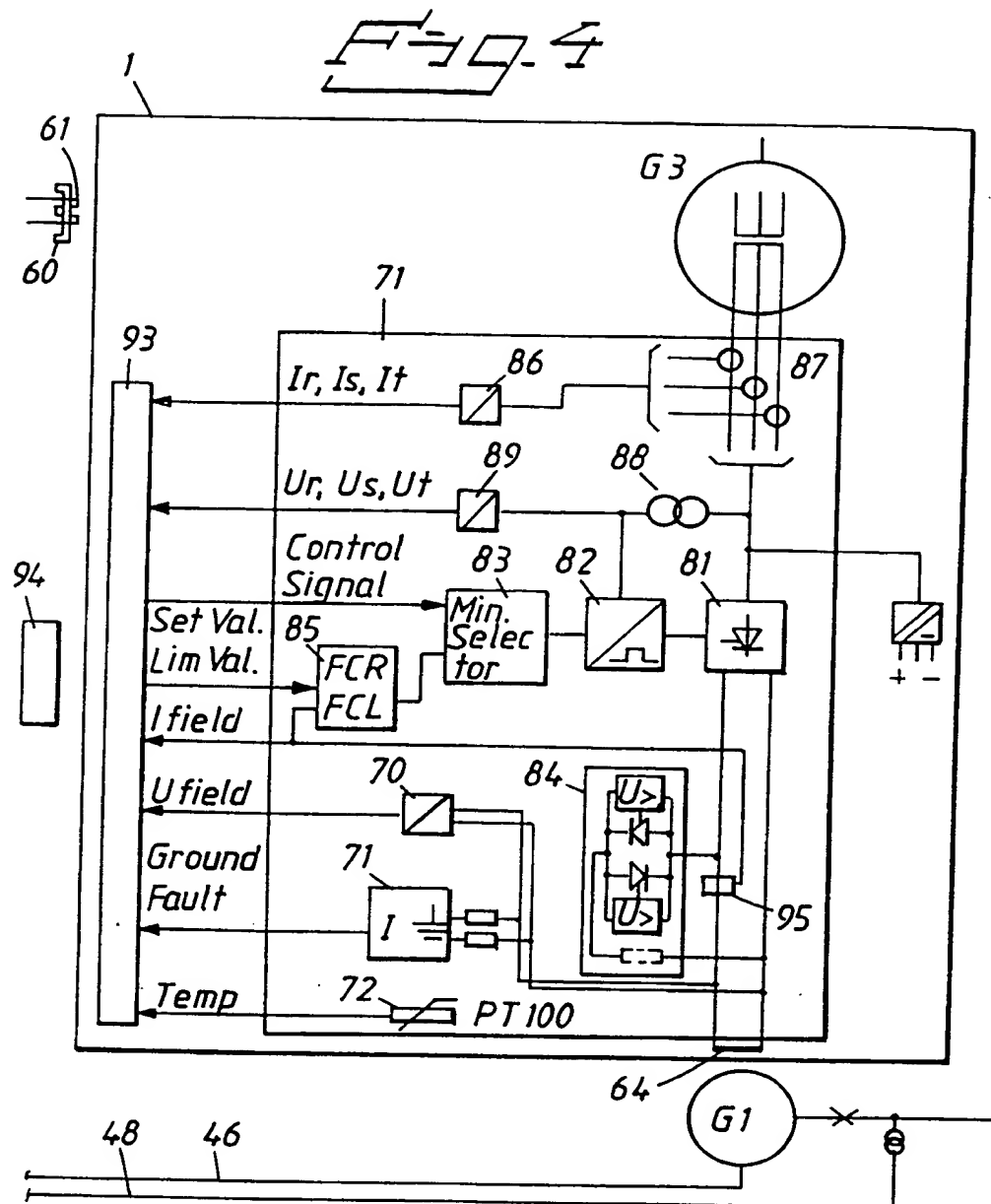
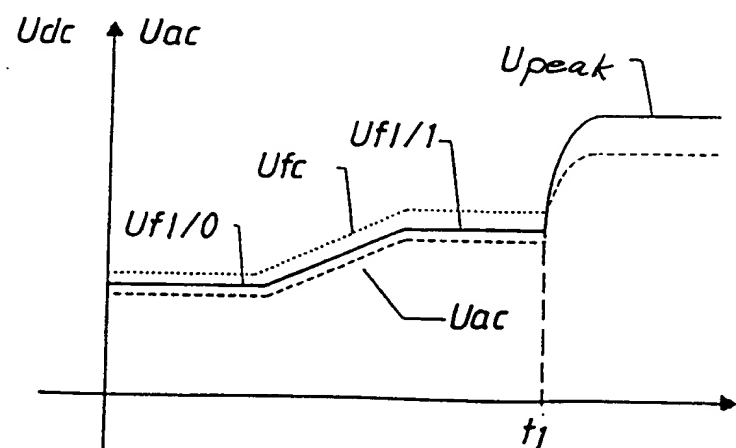


Fig. 5



5 / 5

Fig. 6

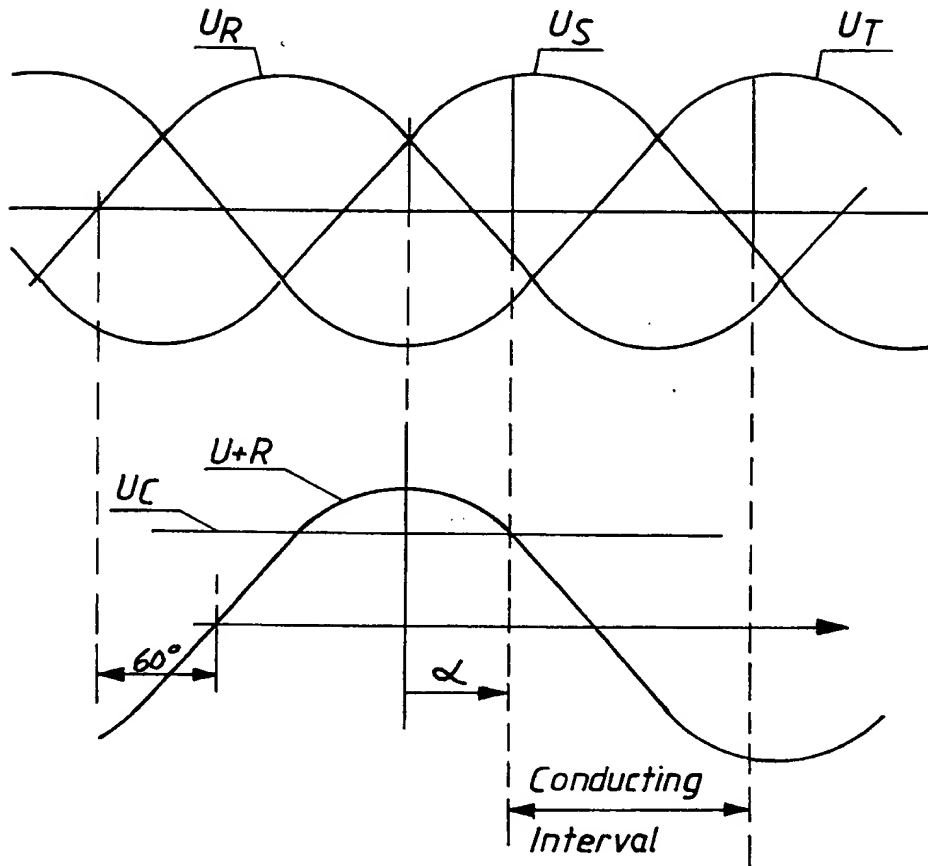
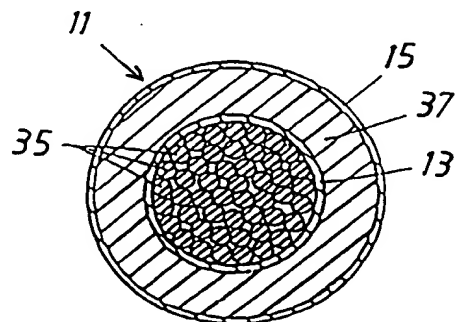


Fig. 7



## INTERNATIONAL SEARCH REPORT

International application No.

PCT/SE 98/01738

## A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H02K 19/36

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H02K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4785138 A (O. BREITENBACH ET AL.), 15 November 1988 (15.11.88), see the whole document --	1-12,20,21, 28,29,32
Y	US 4121148 A (H. PLATZER), 17 October 1978 (17.10.78), see the whole document --	1-12,20,21, 28,29,32
Y	US 4106069 A (J. TRAUTNER ET AL.), 8 August 1978 (08.08.78), see the whole document --	1-12,20,21, 28,29,32
Y	GB 1426594 A (WESTINGHOUSE ELECTRIC CORPORATION), 3 March 1976 (03.03.76), see the whole document --	1-12,20,21, 28,29,32

☒ Further documents are listed in the continuation of Box C.☒ See patent family annex.

## \* Special categories of cited documents:

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier document but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

24 March 1999

Date of mailing of the international search report

25-03-1999

Name and mailing address of the ISA/  
Swedish Patent Office  
Box 5055 S-102 42 STOCKHOLM

Authorized officer

Lars Jakobsson

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/SE 98/01738

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5036165 A (R.K. ELTON ET AL.), 30 July 1991 (30.07.91), see the whole document  -----	1-12,20,21, 28,29,32

# INTERNATIONAL SEARCH REPORT

International application No.

PCT/SE98/01738

## Box I Observations where certain claims were found unsearchable (Continuation of Item 1 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
  
2. ☐ Claims Nos.:  
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
  
3. ☐ Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

## Box II Observations where unity of invention is lacking (Continuation of Item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

See extra sheet.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
  
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:  
1-12, 20, 21, 28, 29, 32

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.  
☐ No protest accompanied the payment of additional search fees.

The internal application is not considered to comply with the requirement of unity of invention.

Claim 1, 10 and 32 describes an electric power plant resp. use of a rotating electric machine comprising a winding with layers of semiconducting properties. A winding with semiconducting properties is previously known from US 4785138. Electric power plants comprising a rotating electric machine with a brushless excitation system with controllable semiconductor elements are previously known from US 4121148, US 4106069 and GB 1426594.

Claim 1, 10, 12 and 32 are considered as a combination of known art. Since no unexpected technical effect has been achieved the combination must be considered as an obvious application of known art. Claim 1,10,12 and 32 therefore lack inventive step.

Since claim 1,10 and 12 lack inventive step, the related dependent claims to claims 1, 10 and 12 will be divided in 9 independent inventions. These inventions have no technical feature in common over the prior art.

Consequently, it appears, a posteori, that 9 independent inventions exist. A partial search has been carried out relating to the first (I) invention according to claims 1-12,20,21,28,29 and 32.

(I) Claims 1-12,20,21,28,29,32 relates an electric power plant with one rotating electric machine comprising a winding and a brushless excitation system with controllable semiconductor elements and provided with an overvoltage protecting circuit.

(II) Claims 13, 22, 25 relates to a power plant with a wireless communication unit.

(III) Claims 14 relates to a power plant with an exciter of synchronous machine type.

(IV) Claim 15 relates to a power plant with an exciter of a permanentmagnet generator type.

(V) Claim 16 relates to a power plant with an exciter of asynchronous machine type with three rotating windings.

(VI) Claims 17-19,23-24,31 relates to a power plant with an exciter with double stator windings for supplying the electric machine or the main machine and an auxiliary power machine.

(VII) Claim 26 relates to a power plant with ground fault detection.

**INTERNATIONAL SEARCH REPORT**

International application No.

PCT/SE98/01738

(VIII) Claim 27 relates to a power plant with temperature transducers.

(IX) Claim 30 relates to a power plant with feed back of the output voltage to the regulator equipment.

INTERNATIONAL SEARCH REPORT  
Information on patent family members

02/03/99

International application No.  
PCT/SE 98/01738

Patent document cited in search report			Publication date	Patent family member(s)		Publication date
US	4785138	A	15/11/88	DE	3543106 A,C	11/06/87
US	4121148	A	17/10/78	AT	340523 A,B	27/12/77
				DE	2714188 A,B,C	17/11/77
				FI	64871 B,C	30/09/83
				FI	771140 A	28/10/77
				FR	2349992 A,B	25/11/77
				GB	1541406 A	28/02/79
				NL	165615 B,C	17/11/80
				NL	7703629 A	31/10/77
				SE	423295 B,C	26/04/82
				SE	7704784 A	28/10/77
US	4106069	A	08/08/78	AT	265977 A	15/11/79
				AT	357216 B	25/06/80
				BR	7703213 A	08/02/78
				CA	1079349 A	10/06/80
				CH	615303 A	15/01/80
				DE	2622309 A,B,C	24/11/77
				GB	1542185 A	14/03/79
				IN	148531 A	28/03/81
				JP	1283918 C	27/09/85
				JP	52140812 A	24/11/77
				JP	60005155 B	08/02/85
				SE	430840 B,C	12/12/83
				SE	7705309 A	20/11/77
GB	1426594	A	03/03/76	AR	194326 A	29/06/73
				AU	5344173 A	19/09/74
				BE	798901 A	30/10/73
				BR	7303124 D	00/00/00
				CA	944815 A	02/04/74
				CH	565476 A	15/08/75
				DE	2319856 A	15/11/73
				FR	2183034 A,B	14/12/73
				JP	49049137 A	13/05/74
				SE	386023 B,C	26/07/76
				US	3748555 A	24/07/73
US	5036165	A	30/07/91	US	5066881 A	19/11/91
				US	5067046 A	19/11/91
				CA	1245270 A	22/11/88
				US	4853565 A	01/08/89